The total amount of solar energy hitting Earth exceeds the total energy consumed by humanity by a factor of over 20,000, yet solar energy accounts for less than 1% of the total energy produced in the United States! While there has been a general shift towards environmental awareness today, we still have a long way to go in creating an environmentally sustainable planet. The only way to truly increase this percentage is to employ solar energy systems on a large, industrial scale. Concentrated Solar Power (CSP) is a technology that may not yet have the same household recognition as rooftop Photovoltaic's (PV), but does have the ability to create a shift in how we generate electricity. While there are still some initial obstacles CSP must overcome, this thermal technology will have the ability to greatly reduce our overall emissions; a typical CSP system can provide enough power to meet the US average electrical demand (500 gigawatts) in clean, emission free, renewable energy.

Overview of Technology:

Concentrated Solar Power (CSP) is a technology that uses mirrors to reflect and concentrate sunlight onto receivers that collect this solar energy and convert it to heat, which is then used to produce electricity through the use of a steam turbine or heat engine that drives a generator to generate electrical power as shown below in Fig. 1[3].

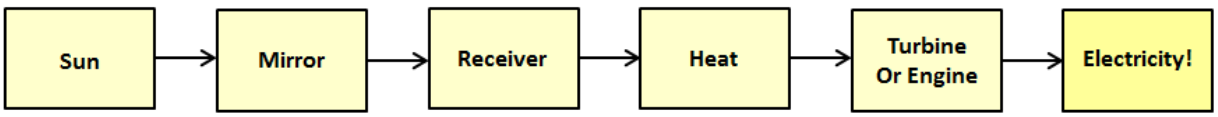

Figure 1: Simplified flow chart of how a typical CSP system works

There are currently three different types of CSP technology; Dish, Troughs, and Towers.

Trough

The first kind of CSP technology developed was the trough technology. Auguste Mochout originally developed it in 1866 when he used parabolic troughs to heat water and produce steam, which ran the first solar steam engine. This trough technology is based on the idea of tracking the sun either by angle of elevation (how far above the horizon the sun is) or by east-west movement. It contains large parabolic troughs, as shown in Figure 2 below, which are fixed to a receiver that can move to follow the sun. The sun's energy is used to heat liquid or steam from the solar field piping, which is then sent to a central power producing system. Trough systems have a demonstrated peak efficiency of about 20%, a mildly effective means for the conversion of solar energy to electricity with a thermal cycle efficiency of 30-40% [7],[11].

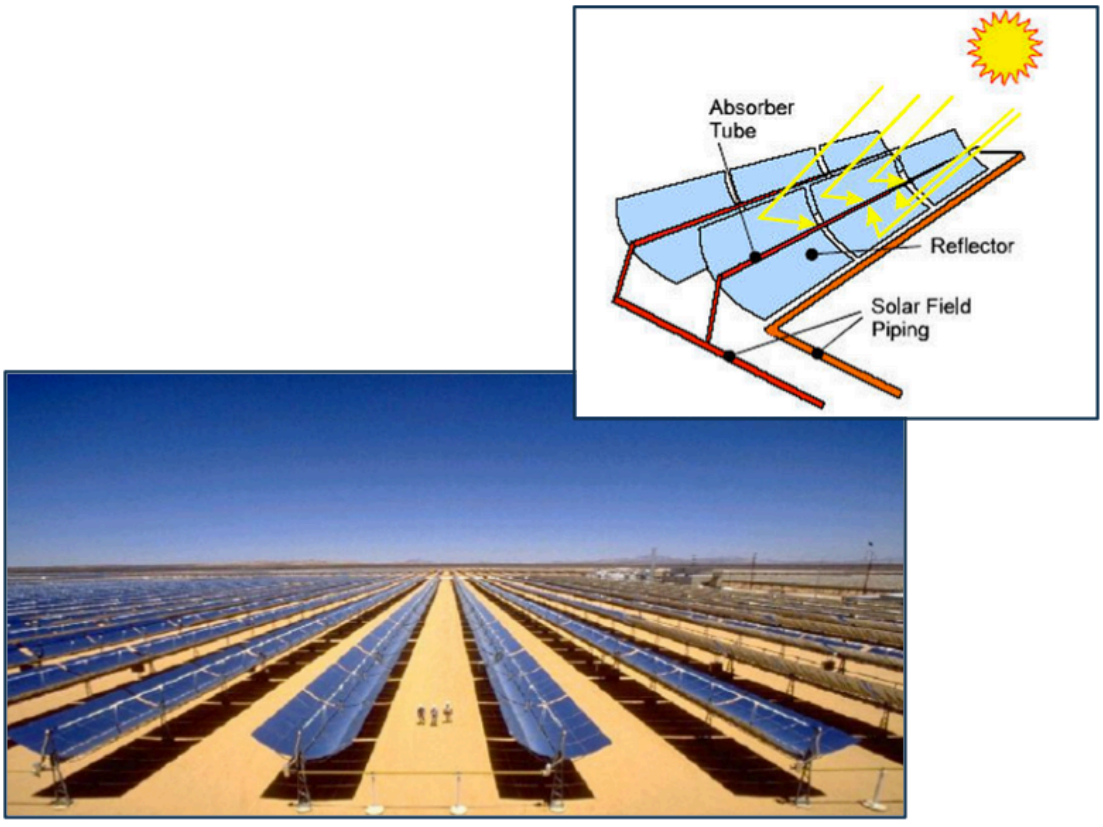

Figure 2: Trough Technology – how it works (upper right) [6] and what it looks like in a picture of the largest CSP parabolic troughs in Dagget California (lower left) [9]

The advantages of the trough technology are its simplicity and ability to capture heat at a low cost, its ability to be combined with energy storage, and its standing as the first CSP technology developed. One of the disadvantages is its use of a single- axis tracking system, which diminishes effectiveness by decreasing concentration factors by 25-100 times [7],[11].

Dish

Unlike the trough systems, which use central power generation, the dish systems are small scale-independent modules, which include a reflector, receiver, and power cycle, as shown below in Figure 3. The power conversion unit, commonly referred to as the PCU, consists of a power-producing engine, as well as a receiver. This small, compact unit is then directly connected to the parabolic reflector. This parabolic reflector is either made up of numerous small mirrors or simply one large parabolic mirror. The most common engine used with this technology is the Stirling engine, which has demonstrated a peak efficiency of about 30-40% for the conversion of solar energy to electricity. [7]

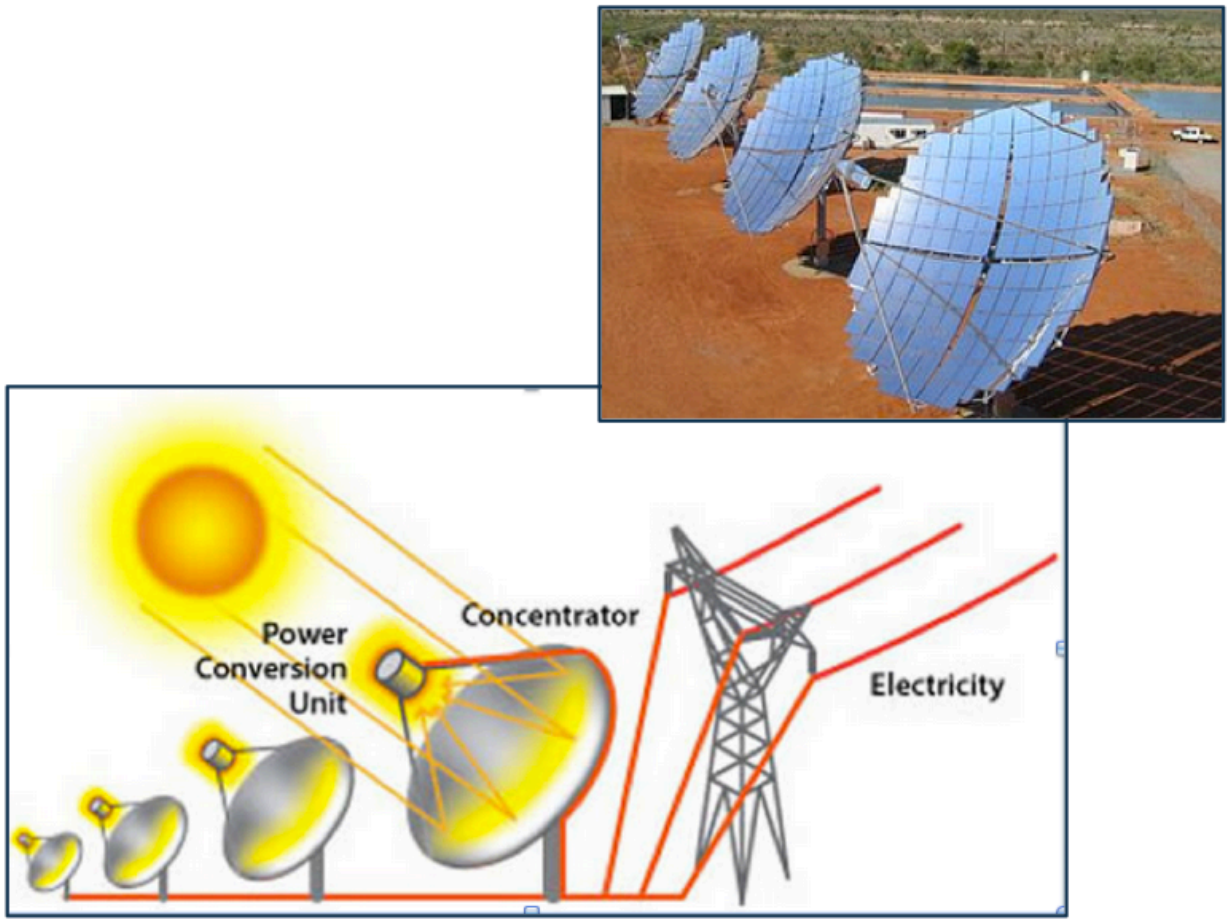

Figure 3: Dish Technology – how it works (lower left) [2] and what it looks like (upper right)[5]

The advantages of the dish technology are its high concentration factor (usually ranging between 1000-3000 times), its modular characteristics and resulting scalability, its high efficiency from the use of a Stirling engine. A disadvantage is its lack of feasibility for power production at small scale due cost inefficiency. Stirling engines are highly effective, but are too expensive to maintain in this context [11].

Tower

Another kind of CSP technology is the tower system – often referred to as "power towers." This system consists of a central receiver and a large field of heliostats. The central receiver is placed on top of a high tower as shown below in Figure 4. Heliostats are mirrors that can track the sun on a two – axis system and therefore can follow the sun individually, and act as a magnifier 3D reflector parabola. One of the key components of this system is that it uses some kind of fluid to transfer the heat from the receiver down to the power cycle on the ground. This fluid is usually molten salt or air and the configurations vary depending on the medium. There are also many different designs of the heliostat field and of the heliostats themselves. Similar to the trough systems, the tower systems have also demonstrated a peak solar efficiency of 20%[7].

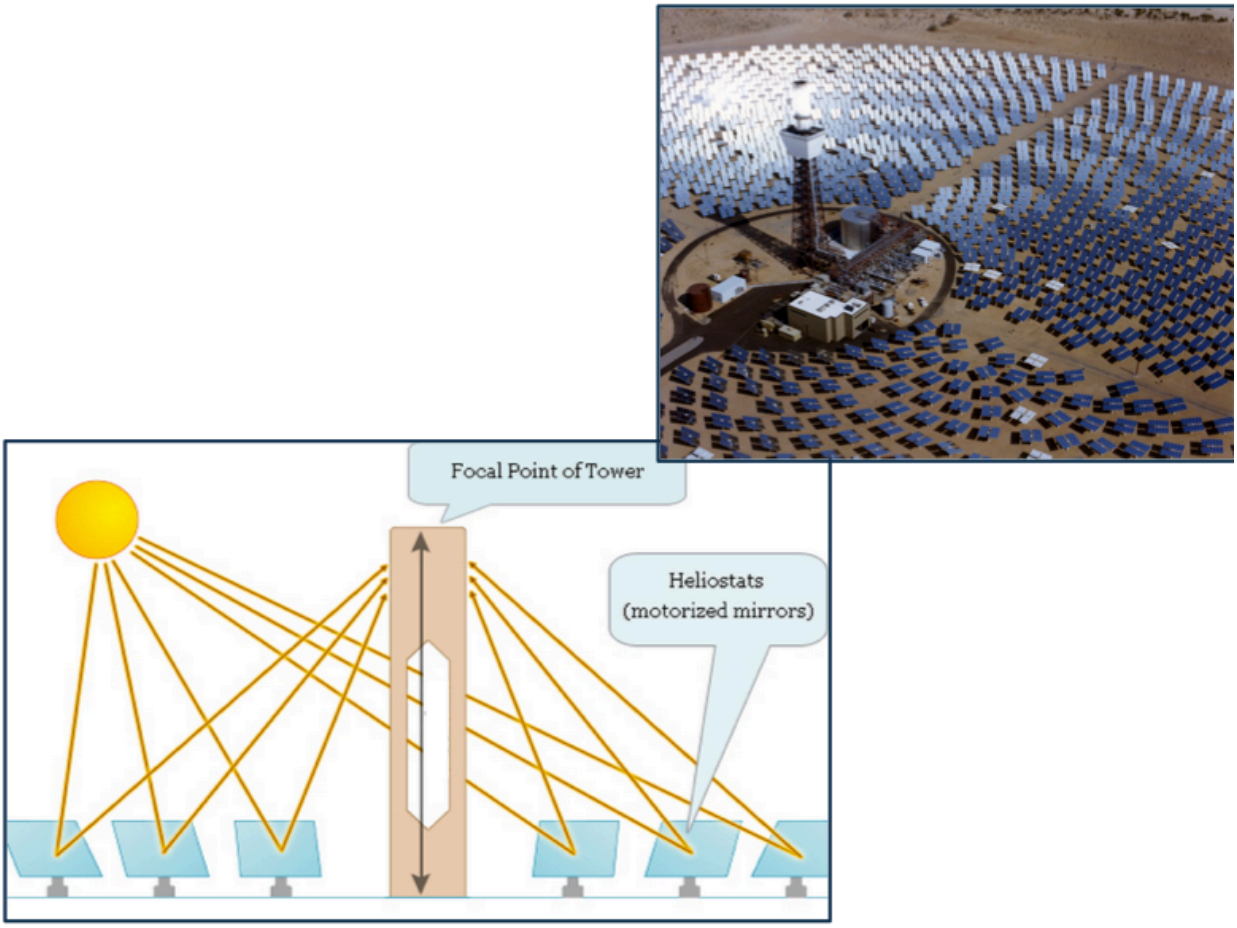

Figure 4: Tower Technology – how it works (lower left) [12] and what it looks like (upper right) [8]
Sources: upper right () lower left()

Some advantages of these power towers are that they are a highly cost-efficient way to produce power and store energy, they have a concentration factor range of 300-1000 times, and the technology has been thoroughly validated by the United States Department of Energy. Some disadvantages are the need for an extensive amount of space, the need for a large tower and complicated receivers, as well as the need for a sophisticated, two-axis tracking system[7],[11].

Obstacles:

One fundamental problem with solar power is the issue of intermittency. While there are plenty of places in the world that receive direct sunlight for many hours a day, none of these places receive direct sunlight at all times due to cloud cover and precipitation. Intermittency is a key reason why current photovoltaic technology will be unable make a significant impact on the energy sector, as current technology lacks the capacity for necessary solar energy storage. According to Olav Hohmyer, a professor from the University of Flensburg, "large and longer term storage solutions are critical to handle the "intermittency challenge" [10]. Current photovoltaic technology is unable to store the sun's energy in an economically viable manner. In order to make solar power a viable alternative to coal power, large scale solar plants with the ability for storage need to become commonplace. Concentrated Solar Power is key to this advancement.

While Concentrated Solar Power may not make sense everywhere, it has been proven to be economically viable in many regions of the world as displayed below in Fig. 5. CSP could be the solution for future of power generation in the United States, especially in the Southwest region. Tower systems using molten salt for storage, as opposed to steam used by alternate technologies, have the ability to replace all of the coal plants in the Southwest. These advancements provide a promising future for energy production.

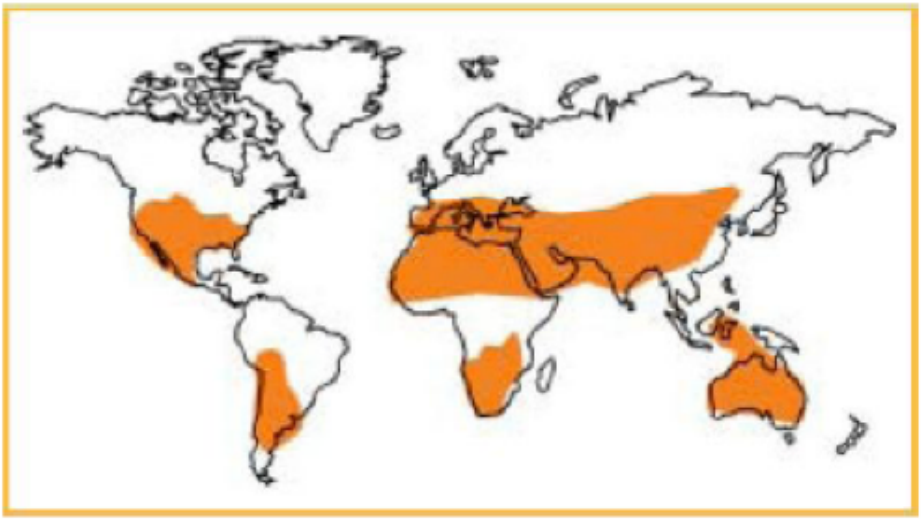

Figure 5: Regions of the world where CSP is economically viable[7]

Future:

Moving forward, Concentrated Solar Power provides a viable option for wide-scale renewable energy, notably molten salt power towers that store solar energy for longer periods and eliminate intermittency issues. As noted by PV-Magazine, many countries have set goals to generate more renewable energy. The European Union plans to generate 20% of its electricity from renewable sources, while the state of California plans to generate 33% of its electricity from renewable sources, both by 2020 [1]. Because of its scalability and storage capacity, Solar is the most viable option for renewable energy.

A key aspect of the molten salt technology used in tower systems is its ability to store energy and allow electricity to be generated on demand. Additionally, this electricity can be controlled in the same manner as a power generator. This system not only has the ability to provide reasonably priced renewable electricity, but also diminishes our reliability on fossil fuels. Figure 6 below displays the effect of energy storage on power production during a 24-

hour cycle, showing how vital storage is and how it will allow solar to potentially replace current power production technologies.

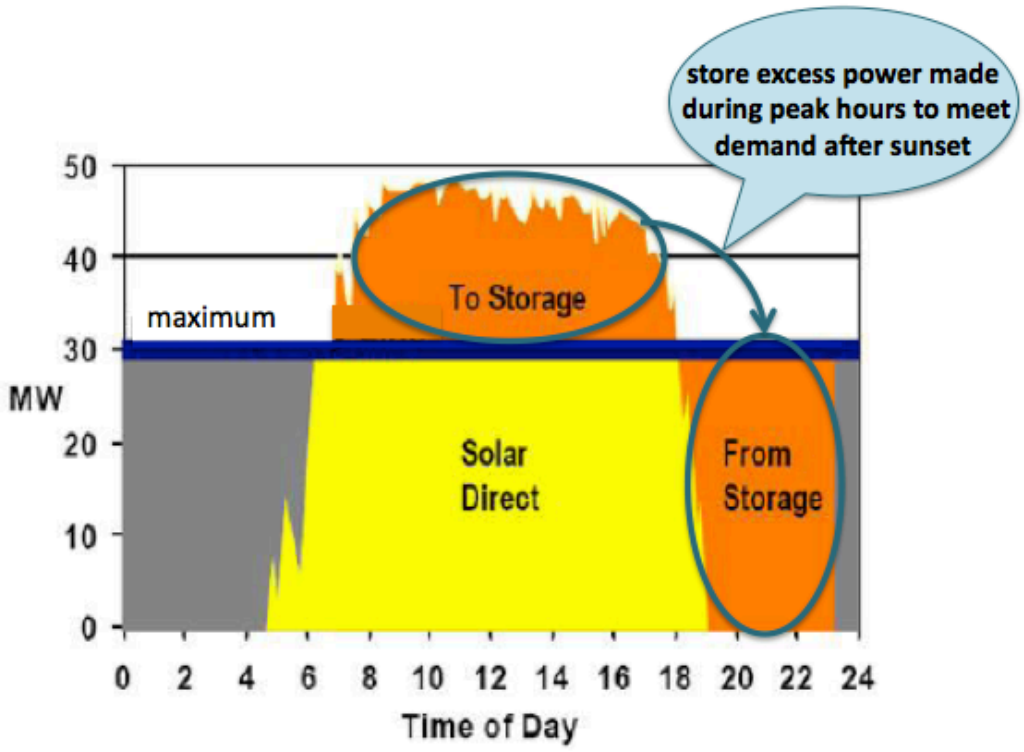

Figure 6: Effect of energy storage on power production during 24 hr cycle [7]

A typical CSP system can provide 500 gigawatt hours per year of clean, emission free, renewable energy. By comparison, four of these systems produce the same amount of power as the Hoover Dam and have the ability to power about 100,000 homes. Because Concentrated Solar Power can be employed on an industrial scale, it can one day replace the coal power plants located in the solar-abundant American Southwest. There are almost 600 coal plants in the United States, which currently produce about 40% of the United States' electricity [4]. By

replacing only half of these plants, we would be able to greatly reduce harmful emissions and make a lasting impact on the energy sector.

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